

Viscosities of binary mixtures of toluene with butan-1-ol and 2-methylpropan-2-ol

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Abstract: The viscosities of binary liquid mixtures of toluene with butan-1-ol and 2-methylpropan-2-ol have been determined at 298.15, 303.15, 308.15, 313.15 and 318.15 K over the whole concentration range. The Hind, Grunberg–Nissan, Wijk, Auslander and McAllister models were used to calculate the viscosity coefficients and these were compared with the experimental data for the mixtures. Excess viscosities were also calculated and fitted to the Redlich–Kister equation. Various thermodynamic properties of viscous flow activation were determined and their variations with composition are discussed.

Keywords: viscosities, binary liquid mixtures, butan-1-ol, 2-methylpropan-2-ol, toluene.

INTRODUCTION

Thermodynamic and transport properties of liquid and liquid mixtures have been used to understand the molecular interactions between the components of the mixture and also for engineering applications. As a continuation of previous work,^{1–4} the viscosities and excess viscosities of binary liquid mixtures of toluene with butan-1-ol and 2-methylpropan-2-ol at 298.15, 303.15, 308.15, 313.15 and 318.15 K as a function of composition are reported. The values of the excess viscosities have been fitted to the Redlich–Kister polynomial equation⁵ to derive the binary coefficients and estimate the standard deviations between the experimental and calculated results. The theoretical viscosities calculated using some existing equations, *i.e.*, those of Hind,⁶ Grunberg–Nissan,^{7–8} Wijk,⁹ Auslander¹⁰ and McAllister,¹¹ have been compared with the measured values for the studied binary liquid mixtures. In addition, the activation energies of viscous flow have been calculated for the binaries toluene with butan-1-ol and 2-methylpropan-2-ol in the temperature range 298.15–318.14 K.

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EXEPRIMENTAL

High purity chemicals (BDH) were employed. All the substances were dried on molecular sieves (Fluka 4 Å) before use. The purity was controlled by chromatographic, density and refractive index measurements. All the mixtures were prepared by mass using an analytical balance (Balanta-Sibiu, România) with a precision of ± 0.1 mg. The possible error in the mole fraction was estimated to be $\pm 2 \times 10^{-5}$. The viscosities of the pure compounds and of the binary mixtures were determined with an Ubbelohde kinematic viscometer,¹² which was kept in the vertical position in a thermostatically controlled water bath (constant to ± 0.05 K). The kinematic viscosity was calculated using the relation:

$$\nu = At - B/t \quad (1)$$

where t is the flow time (± 0.1 s) of a constant volume of liquid through the viscometer capillary; A and B are characteristic constants of the used viscometer, which were determined by taking water and benzene as the calibrating liquids for correction of kinetic energy (Hagen-Poiseuille) deviations. The dynamic viscosity was determined from the equation:

$$\eta = \nu\rho \quad (2)$$

where ρ is the density of the liquid. The densities were determined by the Kahirousch hydrostatic method.¹² The experimental technique has been previously described.² The precision of the densities was ± 0.00005 g/cm³. The accuracy of the viscosity measurement was estimated to be ± 0.0008 mPa s. In all determinations, triplicate experiments were performed for each composition and temperature, and the arithmetic mean was taken for the calculations of the viscosity. The flow times were reproducible to within 1 %. The refractive indices (sodium D line), n_D^{25} , of the pure substances were measured at 298.15 K, using a thermostated Abbe refractometer. The measured viscosities, densities and refractive indices of the pure component liquids are compared with their corresponding literature values.¹³⁻¹⁸ in Table I.

TABLE I. Comparison of experimental viscosities, densities and refractive indices n_D^{25} of the pure liquids together with literature values

Component	Temp./K	Viscosity/mPa s		n_D^{25}		Density/(kg/m ³)	
		Exp.	Lit.	Exp.	Lit.	Exp.	Lit.
Toluene	298.15	0.5561	0.5521 ¹³	1.4938	1.4942 ¹³		
	303.15	0.5314	0.5372 ¹³			856.9	856.6 ¹⁹
	308.15	0.5083					
	313.15	0.4833					
	318.15	0.4630					
Butan-1-ol	298.15	2.5434	2.570 ¹⁴	1.3975	1.3984 ¹⁷		
	303.15	2.2243	2.197 ¹⁴			802.7	802.4 ¹⁹
	308.15	1.9560	1.929 ¹⁵				
	313.15	1.6872					
	318.15	1.4879					
2-Methylpropan-2-ol	298.15	4.3451	4.439 ¹⁶	1.3840	1.3844 ¹⁸		
	303.15	3.3720	3.378 ¹⁶			775.6	775.0 ¹⁹
	308.15	2.6451	2.589 ¹⁶				
	313.15	2.0921					
	318.15	1.6350					

RESULTS AND DISCUSSION

Experimental values of viscosities of mixtures at 298,15, 303,15, 308,15, 313,15 and 318.15 K are listed as a function of mole fraction of toluene in Tables II and III. The results in this study are in close agreement with the work of Nikam *et al.*¹⁹ with regard to these systems at 303.15, 308.15 and 313.15 K. No experimental data were found for the studied mixtures at 298.15 and 318.15 K, with which a comparison of the present values could be made. The experimental values of viscosity were used to calculate the excess viscosity (η^E), defined by the equation:

$$\eta^E = \eta_{\text{exp}} - [x\eta_1 + (1 - x)\eta_2] \tag{3}$$

where η_1 and η_2 are the viscosities of the pure components. The η^E values at 298.15, 303.15, 308.15, 313.15 and 318.15 K for each of the two binary mixtures are also given in Tables II and III. All the values of η^E were negative, indicating that dispersion forces are predominant in these systems. It was observed that, for all mixture, the values of the excess viscosity decrease with increasing temperature and that the η^E values for the mixtures of toluene + 2-methylpropan-2-ol were higher than those observed for the toluene + butan-1-ol system. The dependence of η^E on the mole function was fitted to the Redlich–Kister equation:⁵

$$\eta^E = x(1 - x) \sum_{i=0}^{i=2} A_i (2x - 1)^i \tag{4}$$

where A_i are empirical constants. The values of the coefficients A_i are listed in Table IV, together with the standard deviations σ :

$$\sigma = \left[\frac{\sum (\eta_{\text{exp}}^E - \eta_{\text{calc.}}^E)^2}{m - n} \right]^{1/2} \tag{5}$$

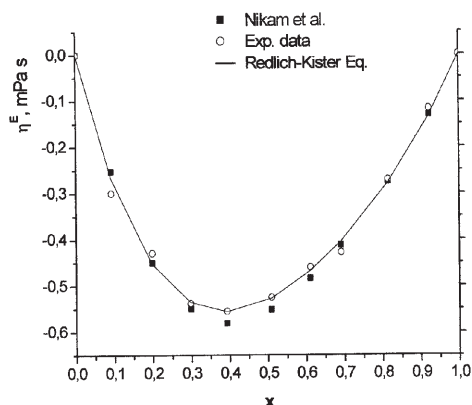


Fig. 1. Excess viscosity of toluene + butan-1-ol at 303.15 K; (O) this work, (■) Nikam *et al.*¹⁹ The continuous curve was calculated from the Redlich–Kister equation.

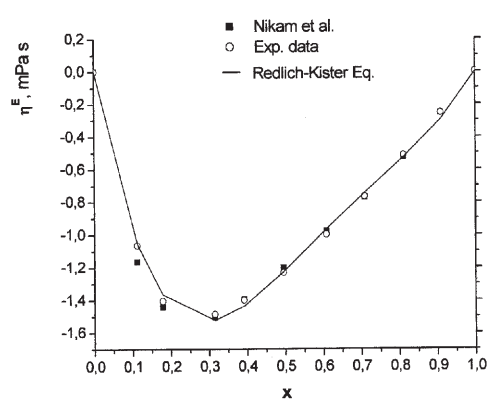


Fig. 2. Excess viscosity of toluene + 2-methylpropan-2-ol at 303.15 K; (O) this work, (■) Nikam *et al.*¹⁹ The continuous curve was calculated from the Redlich–Kister equation.

where m is the number of data points and n is the number of estimated parameters. Figs. 1 and 2 illustrate comparisons between the present η^E values with those calculated using the Redlich–Kister polynomial equation and literature values. There is reasonably good agreement for the two systems and the shapes of the curves also remain identical.

In an attempt to describe the viscosity of binary mixtures, the approaches proposed by Hind:⁶

$$\eta = x_1^2 \eta_1 + x_2^2 \eta_2 + 2x_1 x_2 \eta_{12} \quad (6)$$

Grunberg–Nissan:^{7,8}

$$\ln \eta = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 d \quad (7)$$

Wijk:⁹

$$\lg \eta = x_1^2 \lg \eta_1 + x_2^2 \lg \eta_2 + 2x_1 x_2 \lg \eta_{12} \quad (8)$$

and Auslander:¹⁰

$$x_1[x_1 + B_{12}x_2(\eta - \eta_1)] + A_{21}x_2[B_{21}x_1 + x_2(\eta - \eta_2)] = 0 \quad (9)$$

TABLE II. Viscosities η and excess viscosities η^E of binary mixtures of toluene (x) + butan-1-ol ($1-x$) at different temperatures

x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$	x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$
298.15 K					
0.0000	2.5434	0	0.6110	0.7762	-0.5530
0.0920	2.0102	-0.3504	0.6913	0.6621	-0.4912
0.1987	1.5904	-0.5581	0.8151	0.6052	-0.3184
0.2983	1.2788	-0.6718	0.9218	0.5713	-0.1402
0.3930	1.0843	-0.6789	1.0000	0.5561	0
0.5091	0.8978	-0.6338			
303.15 K					
0.0000	2.2243	0	0.6110	0.7296	-0.4603
0.0920	1.7693	-0.2993	0.6913	0.6258	-0.4282
0.1987	1.4593	-0.4286	0.8151	0.5739	-0.2705
0.2983	1.1809	-0.5384	0.9218	0.5455	-0.1183
0.3930	1.0040	-0.5550	1.0000	0.5314	0
0.5091	0.8372	-0.5252			
308.15 K					
0.0000	1.9560	0	0.6110	0.6784	-0.3931
0.0920	1.5812	-0.2416	0.6913	0.5875	-0.3677
0.1987	1.3229	-0.3454	0.8151	0.5421	-0.2339
0.2983	1.0755	-0.4487	0.9218	0.5196	-0.1019
0.3930	0.9192	-0.4679	1.0000	0.5083	0
0.5091	0.7739	-0.4451			

TABLE II. Continued.

x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$	x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$
313.15 K					
0.0000	1.6872	0	0.6110	0.6325	-0.3191
0.0920	1.3932	-0.1832	0.6913	0.5504	-0.3045
0.1987	1.1988	-0.2492	0.8151	0.5094	-0.1965
0.2983	0.9827	-0.3454	0.9218	0.4920	-0.0854
0.3930	0.8418	-0.3723	1.0000	0.4833	0
0.5091	0.7140	-0.3603			
318.15 K					
0.0000	1.4879	0	0.6110	0.6118	-0.2499
0.0920	1.2924	-0.1012	0.6913	0.5380	-0.2413
0.1987	1.1056	-0.1787	0.8151	0.4964	-0.1561
0.2983	0.9514	-0.2308	0.9218	0.4692	-0.0739
0.3930	0.8198	-0.2653	1.0000	0.4630	0
0.5091	0.7048	-0.2613			

TABLE III. Viscosities η and excess viscosities η^E of binary mixtures of toluene (x) + 2-methylpropan-2-ol ($1-x$) at different temperatures

x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$	x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$
298.15 K					
0.0000	4.3451	0	0.6081	0.7016	-1.3394
0.1121	2.4317	-1.4887	0.7089	0.6352	-1.0239
0.1785	1.7172	-1.9516	0.8115	0.5846	-0.6857
0.3151	1.1128	-2.0383	0.9095	0.5623	-0.3367
0.3919	0.9507	-1.9095	1.0000	0.5561	0
0.4958	0.7975	-1.6690			
303.15 K					
0.0000	3.3720	0	0.6081	0.6472	-0.9977
0.1121	1.9909	-1.0627	0.7089	0.5909	-0.7674
0.1785	1.4623	-1.4027	0.8115	0.5517	-0.5151
0.3151	0.9909	-1.4860	0.9095	0.5336	-0.2549
0.3919	0.8583	-1.4004	1.0000	0.5314	0
0.4958	0.7306	-1.2330			
308.15 K					
0.0000	2.6451	0	0.6081	0.5970	-0.7487
0.1121	1.6301	-0.7755	0.7089	0.5487	-0.5806
0.1785	1.2452	-1.0185	0.8115	0.5206	-0.3905
0.3151	0.8824	-1.0893	0.9095	0.5125	-0.1892

TABLE III. Continued.

x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$	x	$\eta/\text{mPa s}$	$\eta^E/\text{mPa s}$
0.3919	0.7749	-1.0328	1.0000	0.5083	0
0.4958	0.6693	-0.9164			
313.15 K					
0.0000	2.0921	0	0.6081	0.5419	-0.5719
0.1121	1.2822	-0.6296	0.7089	0.5040	-0.4476
0.1785	1.0268	-0.7781	0.8115	0.4956	-0.2910
0.3151	0.7677	-0.8175	0.9095	0.4876	-0.1412
0.3919	0.6855	-0.7761	1.0000	0.4833	0
0.4958	0.6025	0.6920			
318.15 K					
0.0000	1.6350	0	0.6081	0.4999	-0.4224
0.1121	1.0498	-0.4538	0.7089	0.4686	-0.3356
0.1785	0.8744	-0.5514	0.8115	0.4657	-0.2182
0.3151	0.6837	-0.5820	0.9095	0.4646	-0.1115
0.3919	0.6188	-0.5569	1.0000	0.4630	0
0.4958	0.5520	-0.5019			

In the above equations were used the dynamic viscosity of the liquid mixture designated by η , and η_1, η_2 are the dynamic viscosities, and x_1, x_2 , are the mole fractions of the pure components 1 and 2 constituting the liquid mixture; η_{12}, d, A_{21} and B_{12} are interaction parameters (viscosity coefficients) and reflect the non-ideality of the system. The three-body Mc Allister equation:¹¹

$$\begin{aligned} \ln \eta = & x_1 \ln \eta_1^3 + 3x_1^2x_2 \ln \eta_{12} + 3x_1x_2^2 \ln \eta_{21} + x_2^3 \ln \eta_2 - \\ & - \ln[x_1 + x_2M_2/M_1] + 3x_1^2x_2 \ln[(2 + M_2/M_1)/3] + \\ & + 3x_1x_2^2 \ln[(1 + 2M_2/M_1)/3] + x_2^3 \ln[M_2/M_1] \end{aligned} \quad (10)$$

and the four-body McAllister equation:

$$\begin{aligned} \ln \eta = & x_1^4 \ln \eta_1 + 4x_1^3x_2 \ln \eta_{1112} + 6x_1^2x_2^2 \ln \eta_{1122} + \\ & + 4x_1x_2^3 \ln \eta_{2221} + x_2^4 \ln \eta_2 - \ln[x_1 + x_2M_2/M_1] + \\ & + 4x_1^3x_2 \ln[(3 + M_2/M_1)/4] + 6x_1^2x_2^2 \ln[(1 + M_2/M_1)/2] + \\ & + 4x_1x_2^3 \ln[(1 + 3M_2/M_1)/4] + x_2^4 \ln[M_2/M_1] \end{aligned} \quad (11)$$

were also tested, where M_1 and M_2 are the molecular weights of the pure components 1 and 2. The adjustable parameters of the McAllister models are given by $\eta_{12}, \eta_{21}, \eta_{1112}, \eta_{1122}$ and η_{2221} . The parameters which appear in equations 6–11 were estimated using the experimental viscosity data and non-linear regression analysis employing the Levenberg–Marquardt algorithm. Table V shows the calculated parameters and the standard deviations between the experimental values and those obtained using the semi-empirical

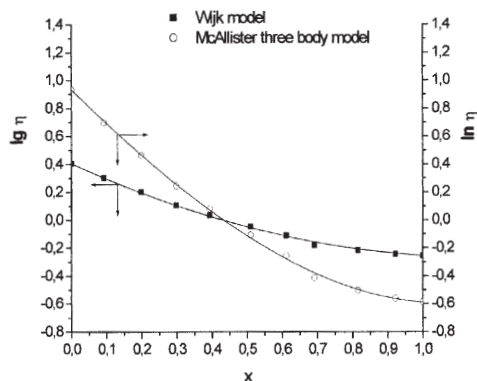


Fig. 3. Comparison of the Wijk and McAllister three body model at 298.15 K for the system toluene + butan-1-ol. The continuous curves were calculated from Eqs. (8) and (10), respectively.

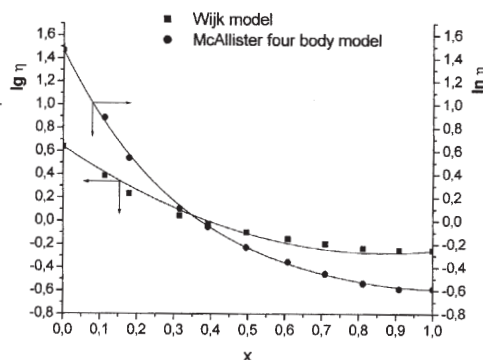


Fig. 4. Comparison of the Wijk and McAllister four body model at 298.15 K for the system toluene + 2-methylpropan-2-ol. The continuous curves were calculated from Eqs. (8) and (11), respectively.

relations of Hind, Grunberg–Nissan, Wijk, Auslander and McAllister. Comparison between the Wijk and the McAllister three body model for the system toluene + butan-1-ol and between the Wijk and the McAllister four body model for the system toluene + 2-methylpropan-2-ol at 298.15 K are illustrated in Figs. 3 and 4, respectively.

TABLE IV. Coefficients A_i , and standard deviations, σ , for η^E from Equation (4) of the binary mixtures at different temperatures

T/K	A_0	A_1	A_2	$\sigma/mPa\ s$
Toluene (x) + butan-1-ol (1-x)				
298.15	-2.57316	1.19362	-0.76007	0.009
303.15	-2.12488	0.83325	-0.55582	0.018
308.15	-1.80502	0.66195	-0.40152	0.015
313.15	-1.45397	0.34353	-0.20064	0.016
318.15	-1.07677	0.05514	-0.06685	0.006
Toluene(x) + 2-methylpropan-2-ol (1-x)				
298.15	-6.57795	6.46842	-5.28582	0.044
303.15	-4.87005	4.54896	-3.61973	0.030
308.15	-3.62328	3.23516	-2.56066	0.023
313.15	-2.72209	2.50539	-2.16256	0.027
318.15	-1.97349	1.70769	-1.57604	0.021

The data presented in Table V and in Figs. 3 and 4 clearly show that the Wijk equation best represents the viscosities of the mixtures of toluene with 1-butanol and the McAllister four-body model best represents the viscosities of the mixtures of toluene with 2-methylpropan-2-ol. The Wijk model gave the best representation of the data for the toluene + butan-1-ol because this system deviates less from ideality than the toluene + 2-methylpropan-2-ol system.

TABLE V. Parameters for the semi-empirical relations of Hind, Grunberg–Nissan, Wijk, Auslander and McAllister

T/K	Equation	$\sigma/m\text{Pas}$	Equation	$\sigma/m\text{Pa s}$
	Toluene (x) + butan-1-ol ($1-x$)		Toluene (x) + 2-methylpropan-2-ol ($1-x$)	
	Hind		Hind	
298.15	$\eta_{12} = 0.2028$	0.083	$\eta_{12} = -1.23657$	0.476
303.15	$\eta_{12} = 0.27217$	0.061	$\eta_{12} = -0.75618$	0.334
308.15	$\eta_{12} = 0.30049$	0.046	$\eta_{12} = -0.42805$	0.237
313.15	$\eta_{12} = 0.34361$	0.028	$\eta_{12} = -0.23594$	0.187
318.15	$\eta_{12} = 0.43225$	0.007	$\eta_{12} = -0.01454$	0.130
	Grunberg–Nissan		Grunberg–Nissan	
298.15	$d = -1.14225$	0.021	$d = -2.78595$	0.086
303.15	$d = -1.04955$	0.023	$d = -2.53073$	0.074
308.15	$d = -1.01364$	0.025	$d = -2.17655$	0.066
313.15	$d = -0.92125$	0.030	$d = -2.17655$	0.073
318.15	$d = 0.6731$	0.035	$d = -1.95019$	0.063
	Wijk		Wijk	
298.15	$\lg \eta_{12} = -0.17279$	0.009	$\lg \eta_{12} = -0.41311$	0.037
303.15	$\lg \eta_{12} = -0.19165$	0.010	$\lg \eta_{12} = -0.42294$	0.033
308.15	$\lg \eta_{12} = -0.22137$	0.011	$\lg \eta_{12} = -0.43643$	0.029
313.15	$\lg \eta_{12} = -0.24432$	0.013	$\lg \eta_{12} = -0.47018$	0.031
318.15	$\lg \eta_{12} = -0.22708$	0.015	$\lg \eta_{12} = -0.48393$	0.027
	Auslander		Auslander	
298.15	$B_{12} = -104.71962$		$B_{12} = -54.90529$	
	$A_{21} = -31.27166$	0.014	$A_{21} = -6.64427$	0.069
	$B_{21} = 0.48049$		$B_{21} = 1.65976$	
303.15	$B_{12} = -112.71147$		$B_{12} = -70.43131$	
	$A_{21} = -36.39199$	0.016	$A_{21} = -9.28425$	0.048
	$B_{21} = 0.41372$		$B_{21} = 1.20858$	
308.15	$B_{12} = -130.37772$		$B_{12} = -89.4178$	
	$A_{21} = -43.90445$	0.015	$A_{21} = -12.58353$	0.030
	$B_{21} = -0.34915$		$B_{21} = 0.89918$	
313.15	$B_{12} = -109.17528$		$B_{12} = -135.93072$	
	$A_{21} = -42.3694$	0.017	$A_{21} = -17.87351$	0.011
	$B_{21} = 0.34799$		$B_{21} = 0.64274$	
318.15	$B_{12} = -114.53743$		$B_{12} = -172.4602$	
	$A_{21} = -55.77301$	0.010	$A_{21} = -24.06716$	0.010
	$B_{21} = 0.27692$		$B_{21} = 0.504$	

T/K	Equation	σ /mPas	Equation	σ /mPa s
	Toluene (x) + butan-1-ol (1-x)		Toluene (x) + 2-methylpropan-2-ol (1-x)	
	McAllister three-body model		McAllister three-body model	
298.15	$\eta_{12} = -0.52402$ $\eta_{21} = 0.11407$	0.017	$\eta_{12} = -0.42622$ $\eta_{21} = -0.54034$	0.025
303.15	$\eta_{12} = -0.58754$ $\eta_{21} = 0.05976$	0.018	$\eta_{12} = -0.50805$ $\eta_{21} = -0.58775$	0.021
308.15	$\eta_{12} = -0.66084$ $\eta_{21} = -0.01607$	0.016	$\eta_{12} = -0.57937$ $\eta_{21} = -0.65869$	0.019
313.15	$\eta_{12} = -0.74239$ $\eta_{21} = -0.07132$	0.016	$\eta_{12} = -0.62663$ $\eta_{21} = -0.8053$	0.023
318.15	$\eta_{12} = -0.76779$ $\eta_{21} = -0.04032$	0.012	$\eta_{12} = -0.71521$ $h_{21} = -0.85575$	0.026
	McAllister four-body model		McAllister four-body model	
298.15	$\eta_{1112} = -0.59896$ $\eta_{1122} = -0.10326$ $\eta_{2221} = 0.26149$	0.016	$\eta_{1112} = -0.57085$ $\eta_{1122} = -0.29553$ $\eta_{2221} = -0.12834$	0.019
303.15	$\eta_{1112} = -0.65437$ $\eta_{1122} = -0.16839$ $\eta_{2221} = 0.19069$	0.017	$\eta_{1112} = -0.63974$ $\eta_{1122} = -0.36945$ $\eta_{2221} = -0.23764$	0.015
308.15	$\eta_{1112} = -0.70554$ $\eta_{1122} = -0.26896$ $\eta_{2221} = 0.11613$	0.016	$\eta_{1112} = -0.70467$ $\eta_{1122} = -0.44361$ $\eta_{2221} = -0.34181$	0.011
313.15	$\eta_{1112} = -0.76484$ $\eta_{1122} = -0.36251$ $\eta_{2221} = 0.05172$	0.017	$\eta_{1112} = -0.78732$ $\eta_{1122} = -0.4751$ $\eta_{2221} = -0.55502$	0.012
318.15	$\eta_{1112} = -0.85624$ $\eta_{1122} = -0.2087$ $\eta_{2221} = -0.13461$	0.018	$\eta_{1112} = -0.87097$ $\eta_{1122} = -0.53303$ $\eta_{2221} = -0.66098$	0.015

The energies of activation of viscous flow for the studied binaries were calculated using the following equations:²⁰

$$\eta = \frac{hN}{V} \exp(\Delta G^\ddagger / RT) \tag{12}$$

$$\Delta G^\ddagger = \Delta H^\ddagger - T\Delta S^\ddagger \tag{13}$$

where ΔG^\ddagger , ΔH^\ddagger and ΔS^\ddagger are the free energy, enthalpy and entropy of activation of viscous flow. The plots of $\ln \eta$ vs. $1/T$ for each of the binaries studied were found to be lin-

ear in the temperature range 298.15 – 318.15 K, and the values of ΔH^\ddagger and ΔS^\ddagger were obtained from the corresponding slopes and the intercepts. Knowing the values of ΔH^\ddagger and ΔS^\ddagger , the corresponding values of ΔG^\ddagger were calculated using Eq. (13). The values of activation energies at 303.15 K are listed in Table VI as a function of composition. The estimated uncertainty of the reported thermodynamic properties is $\pm 2.0\%$. The values of ΔH^\ddagger for the pure components are positive and vary in the order: 2-methylpropan-2-ol > butan-1-ol > toluene, indicating that association and dipole–dipole interactions increase the value of the enthalpy. The values of ΔS^\ddagger for the pure components are negative for toluene and positive for the alcohols, showing that the overall molecular order due to the formation of an activated complex increases for the non-associating component and decreases in case of the alcohols due to the breaking of H-bonds. The values of ΔH^\ddagger and ΔG^\ddagger for the mixtures are positive for all the binaries systems, while the values of ΔS^\ddagger are negative at low alcohol concentration and positive at high alcohol concentration. The positive ΔS^\ddagger values observed in the binaries solutions rich in butan-1-ol or 2-methylpropan-2-ol are indicative of less overall molecular order due to activated complex formation for viscous flow. This type of behaviour has also been observed in other systems.¹³

TABLE VI. Values of ΔG^\ddagger and ΔS^\ddagger at 303.15 K, together with the values of ΔH^\ddagger (approximately constant in the temperature range 298.15 – 318.15 K) for the binary mixtures of toluene + butan-1-ol or 2-methylpropan-2-ol

Toluene (x) + Butan-1-ol (1-x)				Toluene (x) + 2-methylpropan-2-ol (1-x)			
x	ΔH^\ddagger /(J/mol)	ΔS^\ddagger /(J/Mol K)	ΔG^\ddagger /(J/mol)	x	ΔH^\ddagger /(J/mol)	ΔS^\ddagger /(J/MolK)	ΔG^\ddagger /(J/mol)
0.0000	21514.3	19.0	15751.4	0.0000	38798.9	72.3	16888.2
0.0920	17916.7	8.9	15221.0	0.1121	33823.0	60.5	15482.4
0.1987	14746.5	-0.1	14761.7	0.1785	27176.8	40.7	14838.6
0.2983	12389.5	-6.2	14259.9	0.3151	19616.1	18.9	13886.6
0.3930	11752.7	-7.1	13888.9	0.3919	17289.8	12.2	13591.4
0.5091	10282.8	-10.5	13465.9	0.4958	14815.5	5.4	13178.5
0.6110	9888.7	-10.8	13159.7	0.6081	13647.4	2.5	12889.5
0.6913	8685.6	-13.6	12805.4	0.7089	12244.9	-1.5	12699.6
0.8151	8235.9	-14.5	12637.6	0.8115	8964.2	-11.8	12541.4
0.9218	7929.9	-15.2	12540.8	0.9095	7521.7	-16.5	12520.4
1.0000	7360.1	-17.0	12513.7	1.0000	7360.1	-17.0	12513.6

CONCLUSIONS

The viscosities for binary mixtures of toluene with butan-1-ol or 2-methylpropan-2-ol are presented as a function of mixture composition in the temperature range 298.15 – 318.15 K. These results were used to calculate the excess viscosities, which were fitted to the Redlich–Kister polynomial in order to estimate the adjustable parameters and standard deviations between the observed and fitted

quantities. The experimental viscosity data were correlated to the Hind, Grunberg–Nissan, Wijk and Auslander models, as well as to the McAllister three-body and four-body models. The energies of activation of viscous flow for these binaries mixtures were also calculated.

ИЗВОД

ВИСКОЗНОСТ БИНАРНИХ СМЕША ТОЛУЕНА СА БУТАН-1-ОЛОМ И
2-МЕТИЛПРОПАН-2-ОЛОМ

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Вискозности бинарних течних смеша толуена са бутан-1-олом и 2-метилпропан-2-олом одређиване су на температурама 298,15, 303,15, 308,15, 313,15 и 318,15 К у пуном опсегу састава. Модели по Hind-у, Grunberg–Nissan-у, Wijk-у, Auslander-у и McAllister-у коришћени су за израчунавање вредности коефицијента вискозности и оне су упоређене са експерименталним подацима за смеше. Израчуната су повећања вредности вискозности и оне су фитоване по Redlich–Kister-овој једначини. Одређена су различита термодинамичка својства активације вискозног тока и разматране њихове промене са саставом смеша.

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